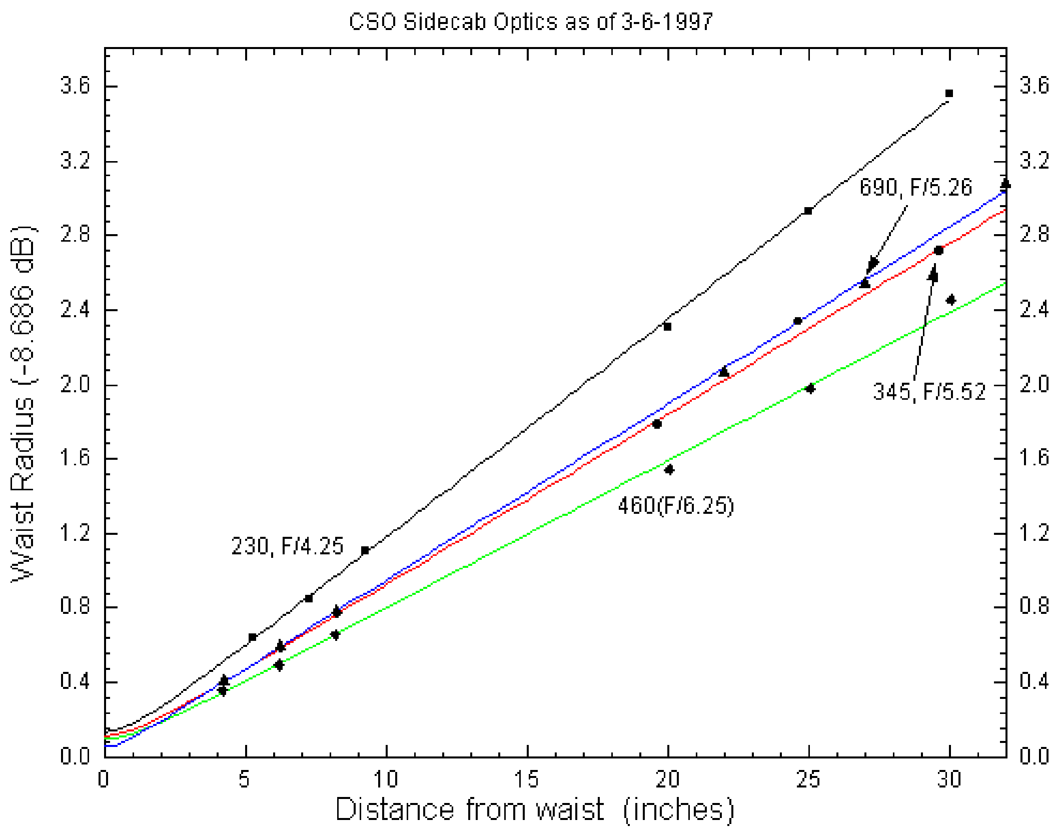
CSO Sidecab Optics, Problems and Solutions

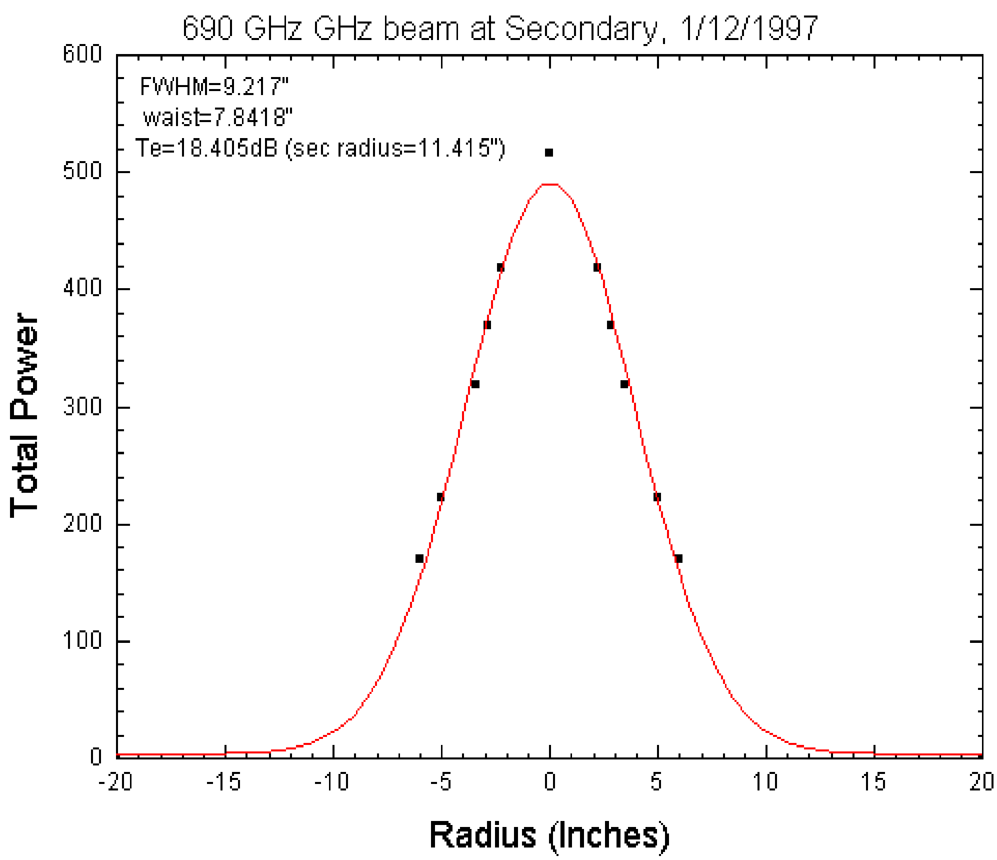
Jacob Kooi, March, 1997

The sidecab optics have been designed using geometric optics. Gausian analyses of the optics chain shows that the 230-690 are **not** in this limit, and that some of the problems observed with the CSO optics are directly related to the latter assumption. To verify the theory we have made careful measurements of the beams on the fifth, third and secondary mirrors. The data appears to fit the theory reasonably well, bearing in mind the following confidence levels:

1) The f-number of the Receiver beam is accurately determined by simply measuring the beam waist (e^{-2}) at various distances from the Local Oscillator optics plate. From lab measurement it is known that the eccentricity of the sidecab receiver beams is in the order of 1.1-1.2. As it turns out the geometric limits assumption aggravates the situation on the secondary. Table I and II tabulate the measured and simulated data.



2) The Edgetaper on the secondary is determined by measuring the Total Power with a wide range of cold loads at the chopping secondary. Fitting a Gausian to this data and knowing the size of the secondary gives the power coupled onto it. The fit to the data appear to be reasonable, giving a good confidence in the measurement.



3) The Cassegrain focus offset is determined by fitting a Gausian beam propagating between the tertiary mirror and the chopping secondary mirror. The fit gives a measurement for the Cassegrain focus waist (wo) and focus offset, ?foc. The error bars appear to be in the order of +- 0.4".

4) Least confident is the determination of d5i, the distance from the receiver waist to the center of the fifth. The Receiver focus is determined, like the Cassegrain focus offset, indirectly by fitting a Gausian mode beam to the data. Error bars on the data appear to in the order of +- 0.4"

Table 1. 230-690 Beams at the Fifth Mirror

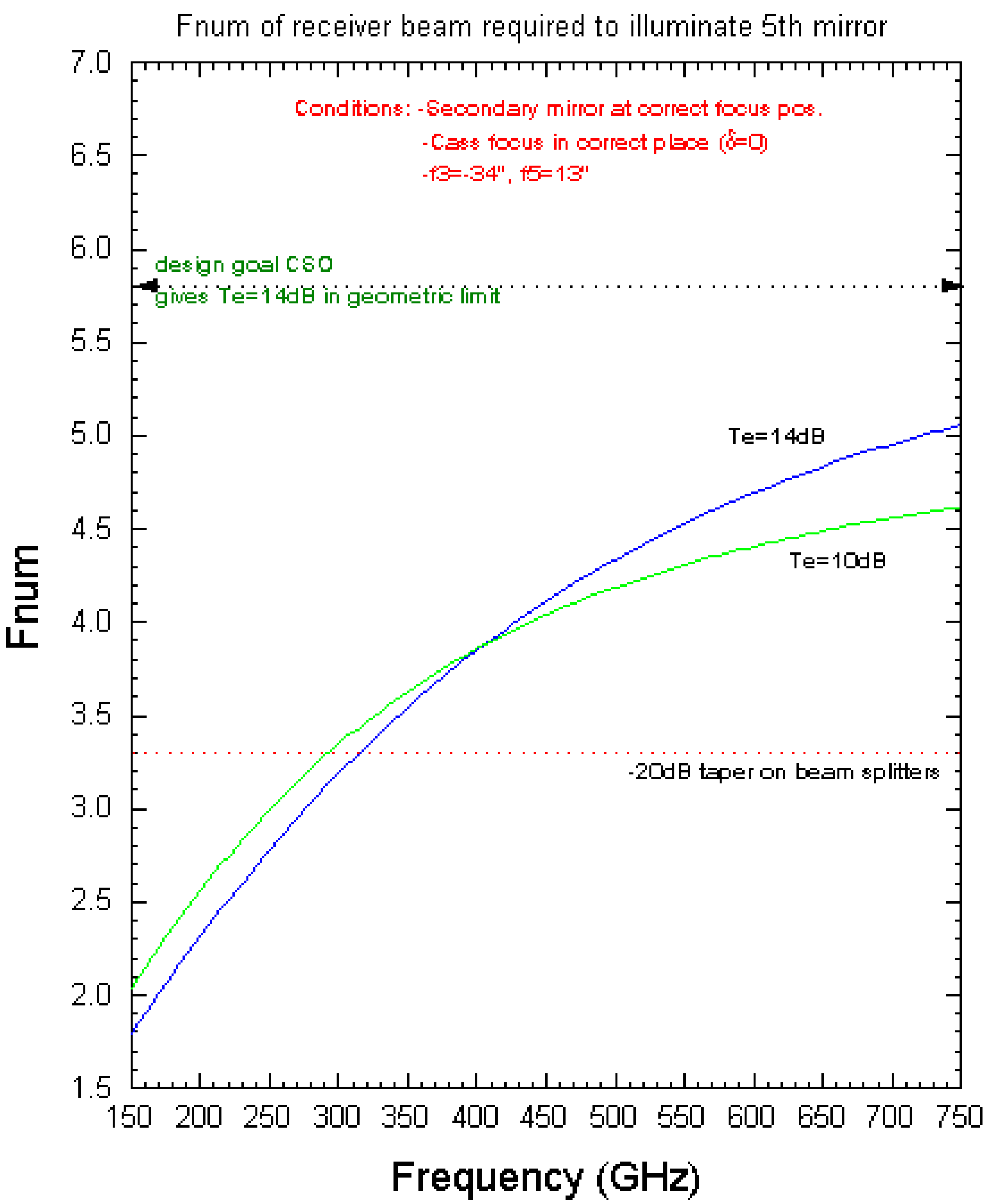
Frequency (GHz)	Rx beam Measurements at Fifth Mirror			Simulated Rx Beams at the Fifth Mirror (from Secondary data)		
	Fnum	d5i (inches)	wo (mm)	Fnum	d5i (inches)	wo (mm)
230	**4.15**	**13.4**	**3.45**	**4.36**	**13.45**	**3.618**
345	**5.56**	**13.6**	**3.08**	**5.95**	**13.89**	**3.291**
492	**6.65**	**13.4**	**2.58**	**6.76**	**13.45**	**2.625**
690	**5.26**	**13.5**	**1.46**	**5.26**	**13.51**	**1.455**

Table 2. 230-690 Beams on the Chopping Sec ondary

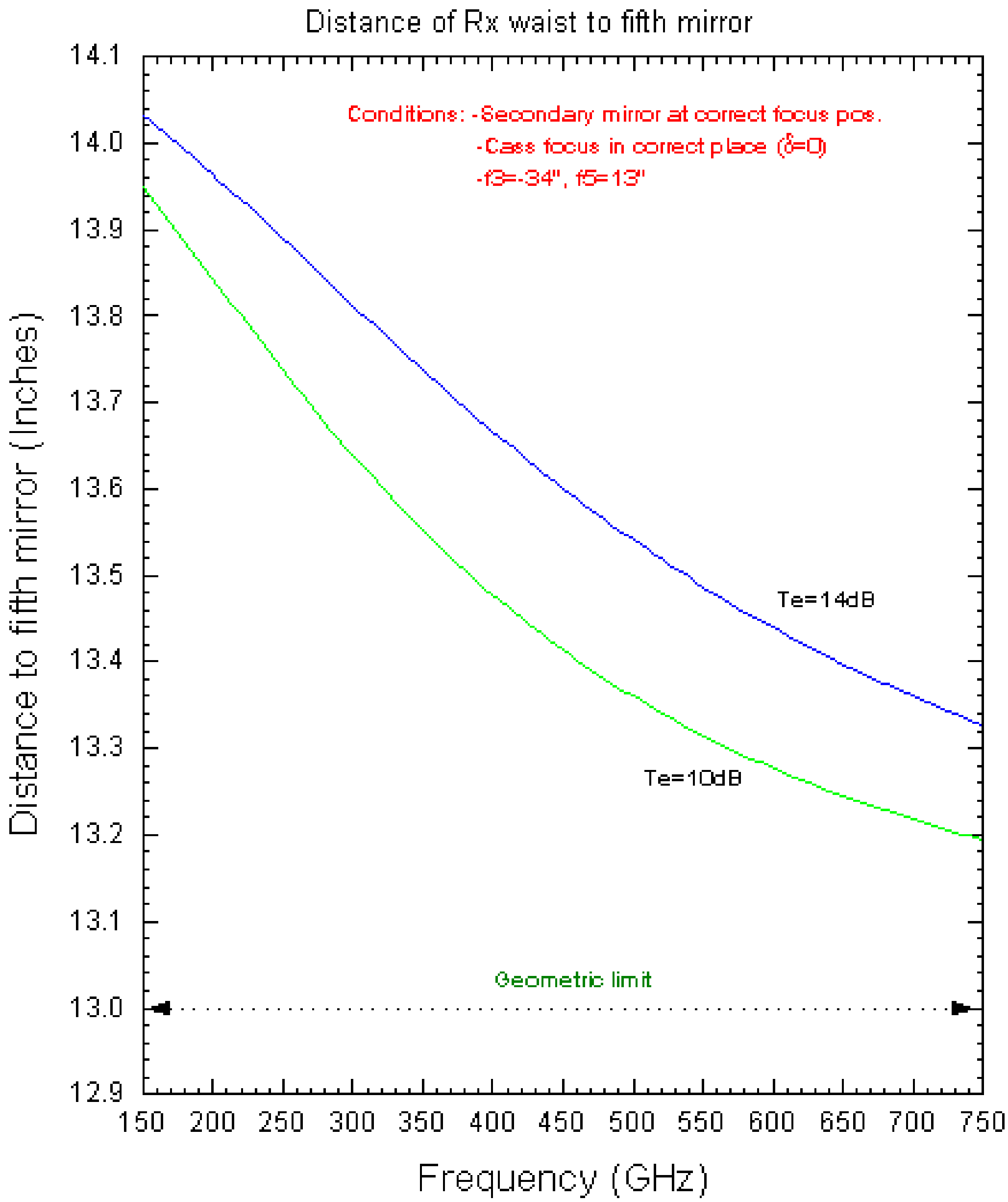
Frequency (GHz)	Beam Measurements on the Tertiary and Secondary Mirrors			Simulated Rx beams at Secondary Mirror (from Fifth mirror data)		
	Te(dB)	?foc (inches)	wa (inches)	Te(dB)	?foc (inches)	wa (inches)
230	**4.89**	**4.77**	**15.225**	**4.90**	**4.185**	**15.198**
345	**7.62**	**6.89**	**12.191**	**7.64**	**5.52**	**12.177**
492	**9.78**	**5.27**	**10.760**	**9.67**	**5.03**	**10.822**
690	**18.41**	**0.47*****	**7.842**	**18.12**	**0.48**	**18.121**

*??foc at 690 GHz was derived from the simulated data since beam measurements on the tertiary seem to be incorrect.

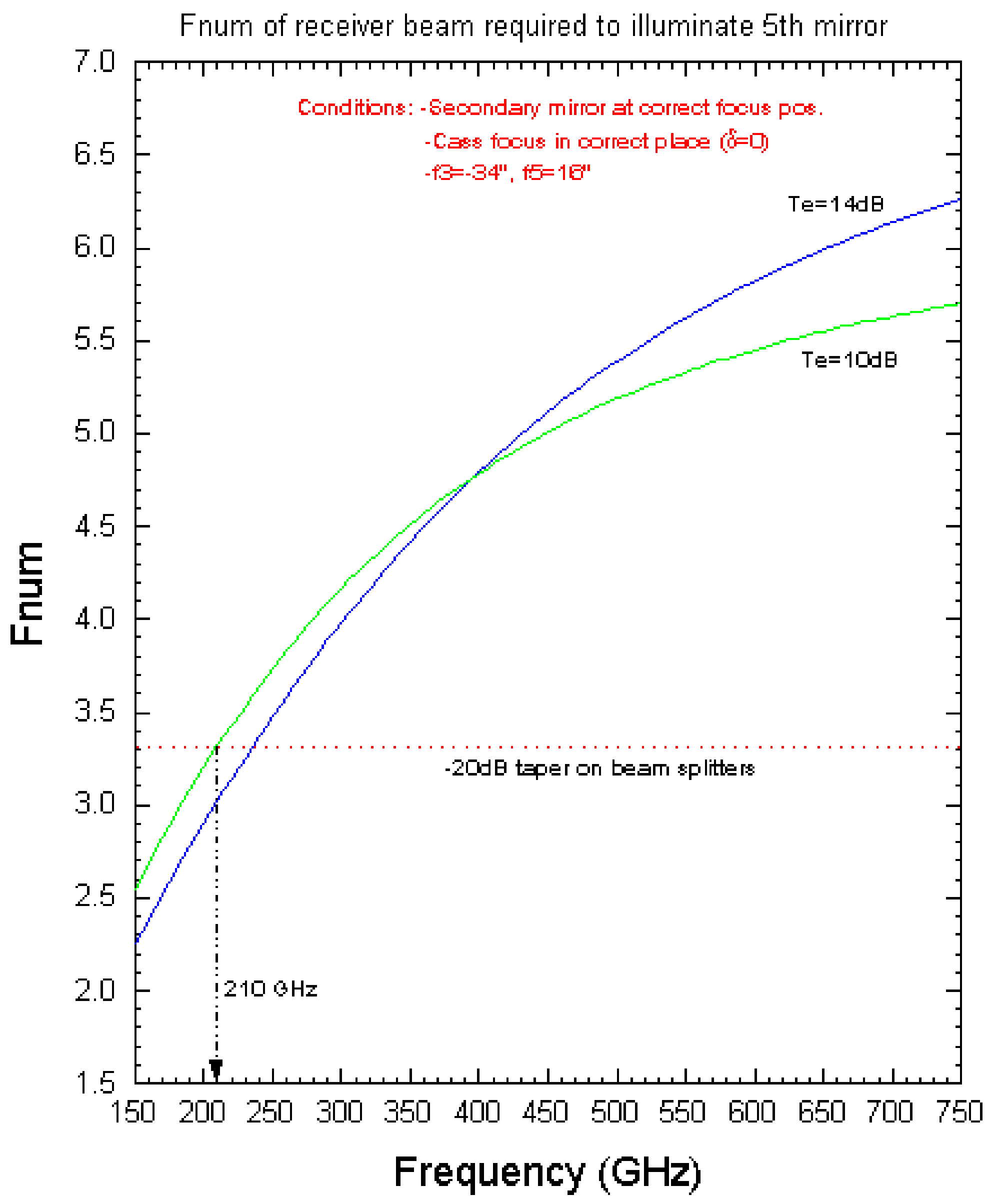
Below we present the required receiver beam to achieve a 14dB edgetaper on the chopping secondary, with the condition that the Cassegrain focus in **exactly** the right place. We plot here the required f-number of the receiver beam for both -10dB and -14dB illumination of the secondary. Please note that a receiver beam with a f-number less than 3.33 starts to seriously vignette on the beamsplitter (-20dB). **This means that in practice we cannot achieve a match for 230 Rx!** The geometric limit design goal is shown for a F4.64 beam defined at the -14dB down in power level.



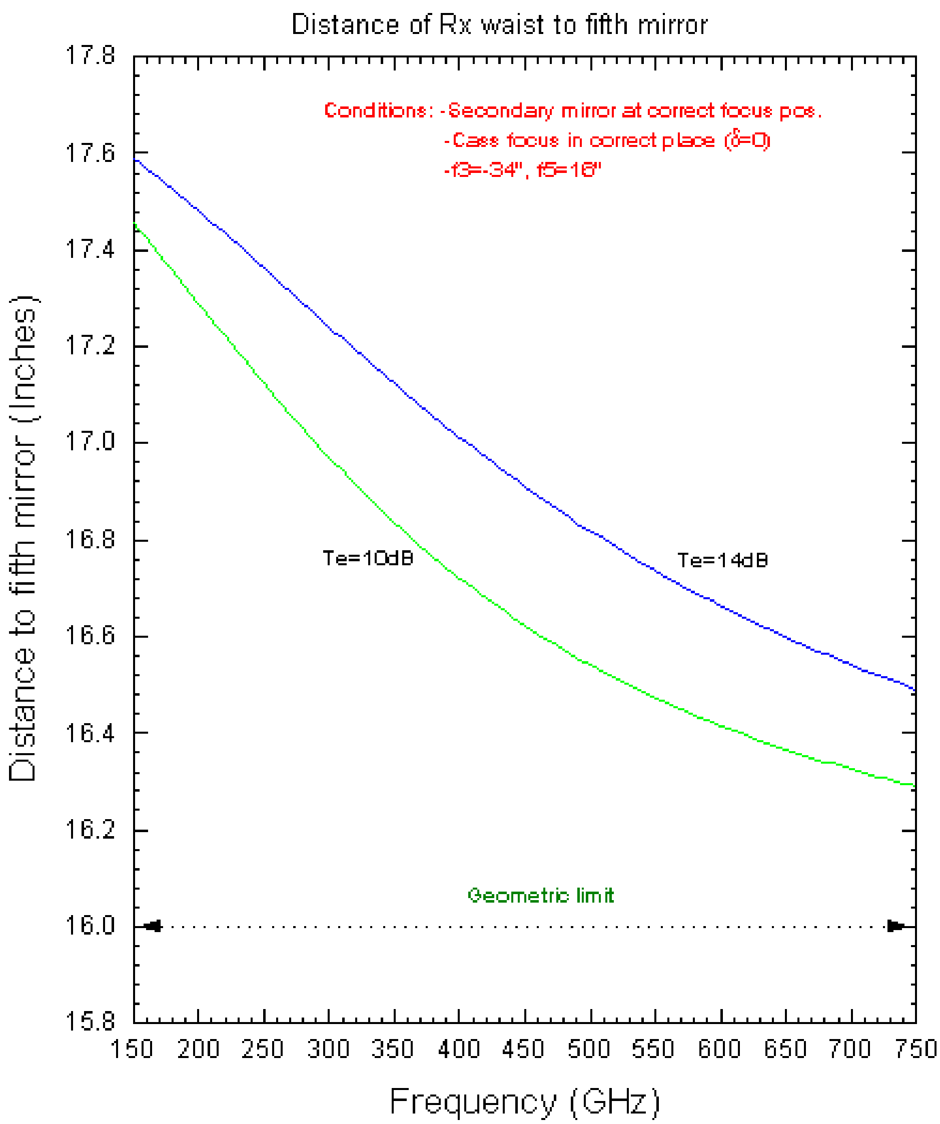
Next we show the required distance from the 5th mirror to achieve the condition where the Cassegrain focus offset is zero. The two plots shown correspond to the -10dB and -14dB secondary edgetaper illumination. I have plotted the geometric limit (13") as a reference.



From the above discussion it is clear that modifying 230 GHz receiver beam alone is not sufficient. If however the focal distance of the fifth mirror is increased from 13" to 16" we show that the required conditions of 14dB secondary edgetaper and proper Cassegrain focus can in fact be satisfied! Increasing the fifth mirror focal length to 16" does however require the 230/492 and 345/665 cryostats to move about 3-4 inches away from the current position, a very painful proposition. The results for a 16" fifth mirror focal length are shown below. Please note that these results are in agreement with independent calculations by Richard Chamberlin.

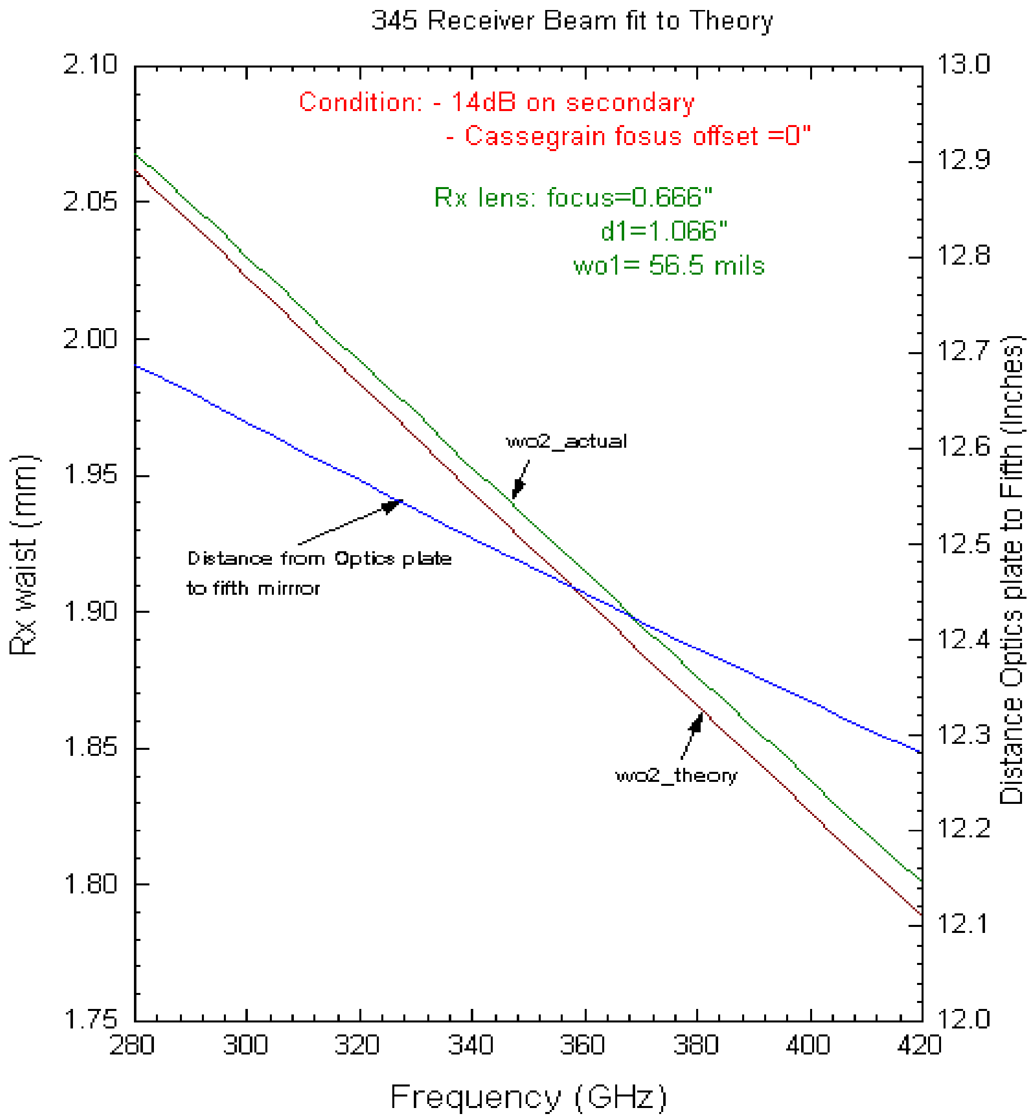


Regardless of weather a new fifth mirror is machined, it is apparent that the position of the receiver cryostat is a function of frequency. Fortunately the hardware is setup to move the dewars in and out of focus. As part of the sidecabinet optics fix, a focus look up table (or function) should be implemented that puts the cryostat at the correct position for each line frequency. The data below represents a **16"** fifth mirror focal length!



Considering the difficulty of changing to a longer fifth mirror focal length (physically re-mounting the cryostats) we have done the analyses on the 230-690 receivers assuming a 13" fifth mirror focal length. **Please note** that in the past frequency independent optics was used, but the analyses clearly shows the opposite is needed.

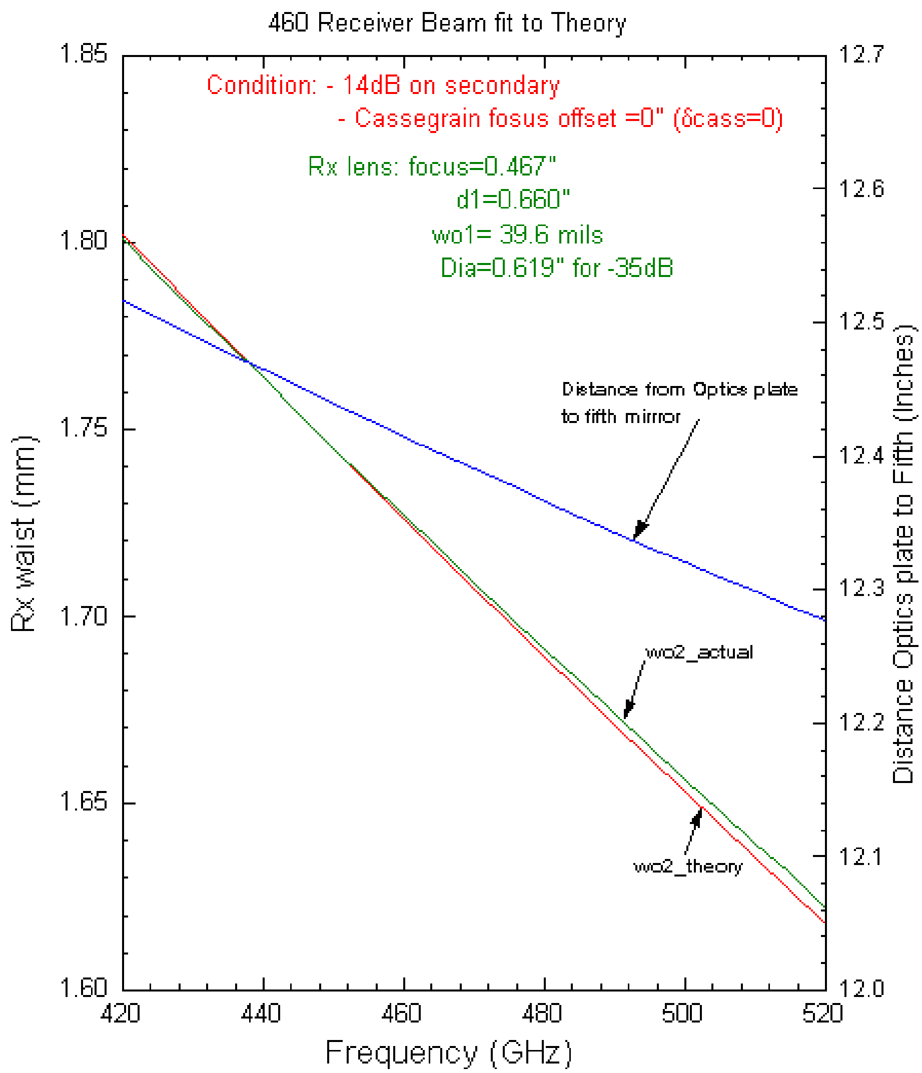
The 345 GHz mixer waist is determined by the horn aperture and is about 56.5 mils. Using this information we calculate a good fit the theoretical required beam waist with the following rx-lens parameters: Focal length of 0.666”, with a 1.066” distance between the horn aperture plane and the lens (d1).



Next we calculate edgetaper of the beam at the different aperture planes in- and outside the dewar. The results tabulated below are for 280-and 420 GHz.

Stage	Taper (dB)	Aperture Dia.(Inches)	Distance (inches)
12K	116 thu 273	1.000	-0.634 thru -0.431
77K	308 thru 324	1.000	-0.126 thru -0.330
290K	248 thru 279	1.650	0.794 thru 0.998
Beam Splitter	28.7 thru 42.6	1.950	3.205 thru 3.408
Fifth mirror	35.1 thru 60.9	9.250	13.85 thru 13.68

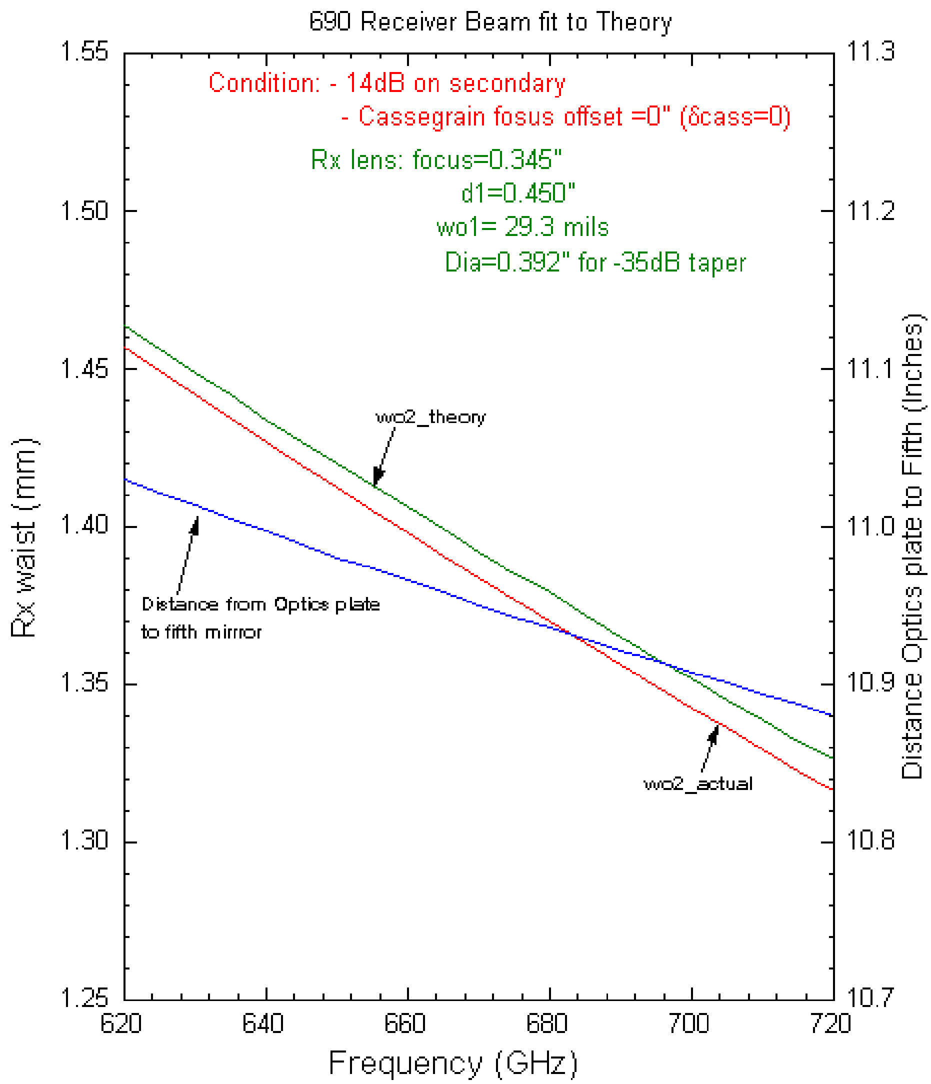
The 460 GHz mixer waist is determined by the horn aperture and is about 39.6 mils. Using this information we calculate a good fit the theoretical required beam waist with the following rx-lens parameters: Focal length of 0.467", with a 0.660" distance between the horn aperture plane and the lens (d1).



Next we calculate edgetaper of the beam at the different aperture planes in- and outside the dewar. The results tabulated below are for 420- and 520 GHz.

Stage	Taper (dB)	Aperture Dia.(Inches)	Distance (inches)
12K	179 thru 275	1.000	-0.667 thru -0.547
77K	419 thru 466	1.000	-0.094 thru -0.215
290K	414 thru 419	1.650	0.762 thru 0.882
Beam Splitter	51.5 thru 57.4	1.950	3.172 thru 3.293
Fifth mirror	62.7 thru 78.9	9.250	13.64 thru 13.54

The 690 GHz mixer waist is determined by the horn aperture and is about 29.30 mils. Using this information we calculate a good fit the theoretical required beam waist with the following rx-lens parameters: Focal length of 0.385”, with a 0.450” distance between the horn aperture plane and the lens (d1).

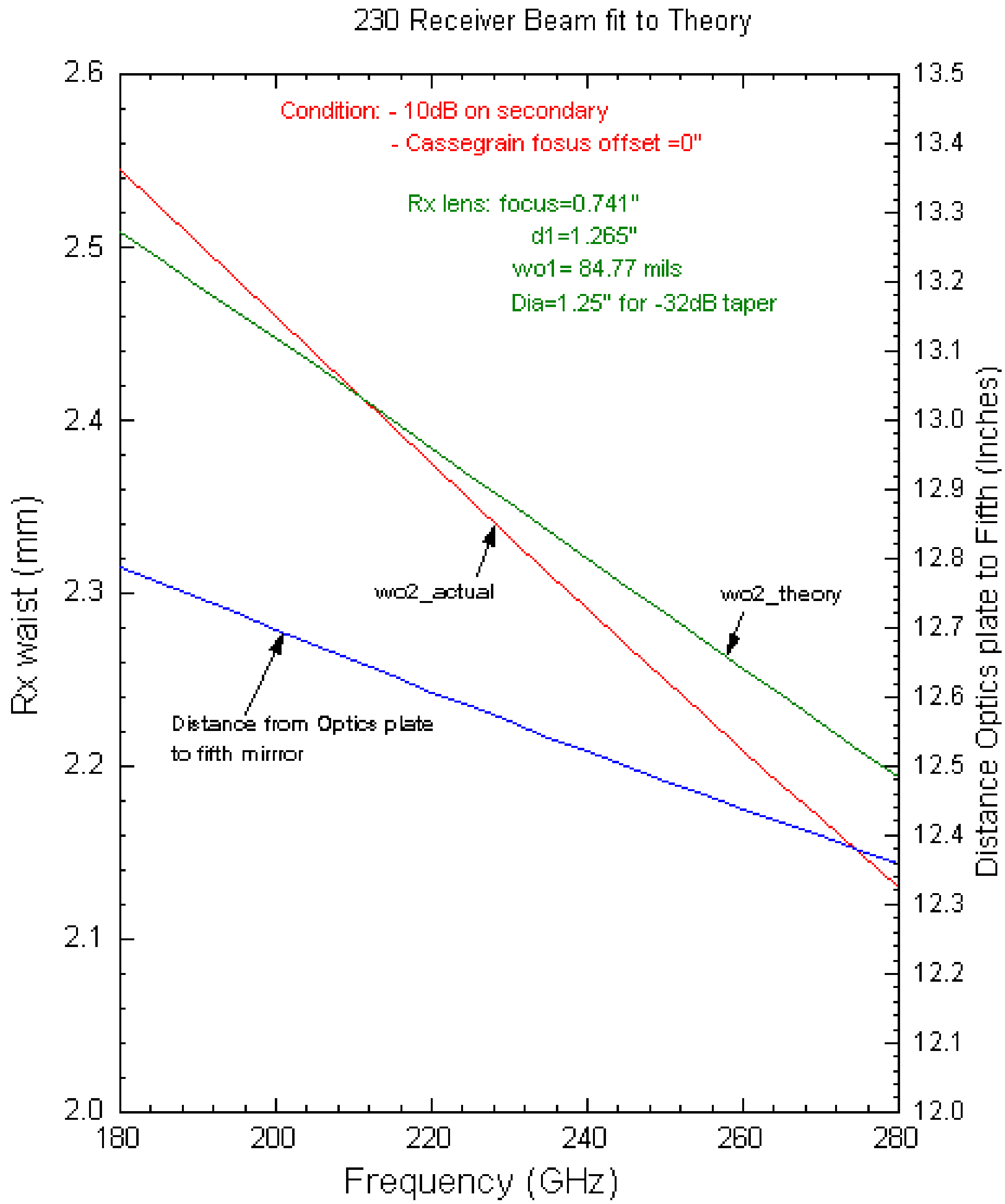


The edgetaper of the beam at the different aperture planes in- and outside the dewar from 620-720 GHz are tabulated below.

Stage	Taper (dB)	Aperture Dia.(Inches)	Distance (inches)
12K	648 thru 745	1.000	0.076 thru 0.150
77K	194 thru 196	1.000	0.838 thru 0.912
290K	206 thru 211	1.650	1.506 thru 1.580
Beam Splitter	47.2 thru 50.2	1.950	3.916 thru 3.990
Fifth mirror	91.9 thru 99.2	9.250	13.42 thru 13.57

The 230 GHz mixer waist is determined by the horn aperture and is about 84.7 mils. Using this information we calculate a reasonable fit to the theoretical required beam waist with the following rx-lens parameters: Focal length of 0.741", with a 1.265" distance between the horn aperture plane and the lens (d1).

Note: Vignetting is a serious problem at the beamsplitter and fifth mirror since a 'fast' beam is required. To minimize the power lost in hot spillover, we have designed to beam to give a 10dB edgetaper at the chopping secondary!



The edgetaper of the beam at the different aperture planes in- and outside the dewar at 180- and 280 GHz are tabulated below. The results are for a proper Cassegrain focus and 10 dB edgetaper on the secondary.

Stage	Taper (dB)	Aperture Dia.(Inches)	Distance (inches)
12K	69.2 thru 167	1.000	-0.696 thru -0.483
77K	217 thru 243	1.000	0.066 thru 0.278
290K	175 thru 195	1.650	0.734 thru 0.947
Beam Splitter	18.3 thru 27.4	1.950	3.143 thru 3.356
Fifth mirror	22.4 thru 38.0	9.250	13.88 thru 13.67

From the above discussion it should be clear that it is **NOT** possible to achieve a proper match for to the Sidecab optics with the 230 GHz receiver. For clarity I have included the results at 230 GHz below. (10dB Edgetaper on the Secondary)

Stage	Taper (dB)	Aperture Dia.(Inches)	Distance (inches)
12K	112.3	1.000	-0.585
77K	233.9	1.000	0.179
290K	187.7	1.650	0.847
Beam Splitter	23.5	1.950	3.257
Fifth mirror	30.16	9.250	13.779

Lastly, a better fit to the theoretically required 230 GHz receiver waist is possible for a longer focal length mixer lens. Unfortunately the diameter becomes so large that it no longer fits inside the cryostat.

Single Sideband Optics

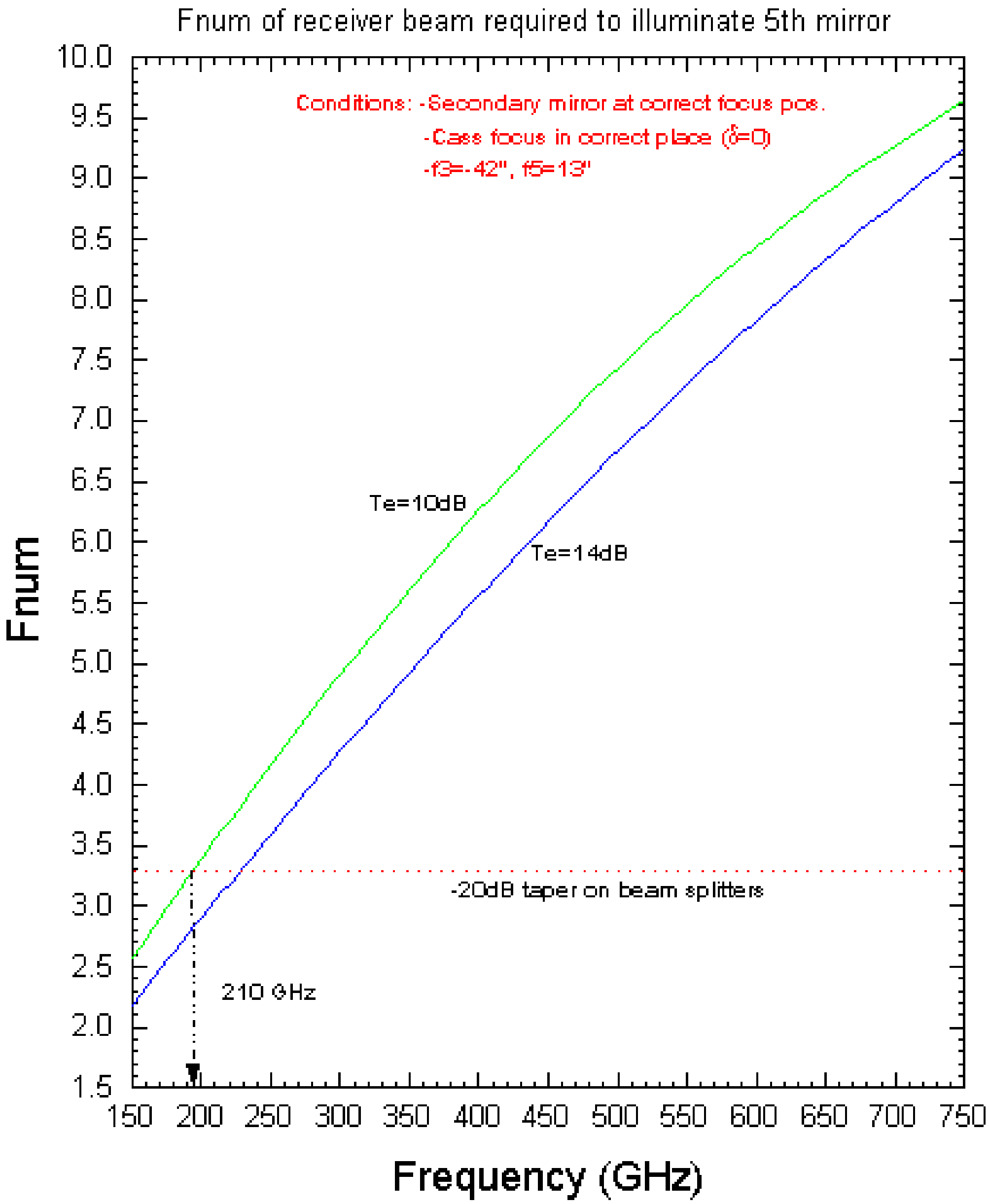
The suggested changes the receiver optics will in the ideal case, give an frequency independent f/33 beam with it's waist 34" in front of the tertiary mirror, in the elevation tube. The SSB filter is situated close to this spot and has 10cm diameter wire grids.
The correct receiver beams have a waist radius of 27.5mm, giving a thru-put of 99.8% (-29.6 dB).

Optics Alignment

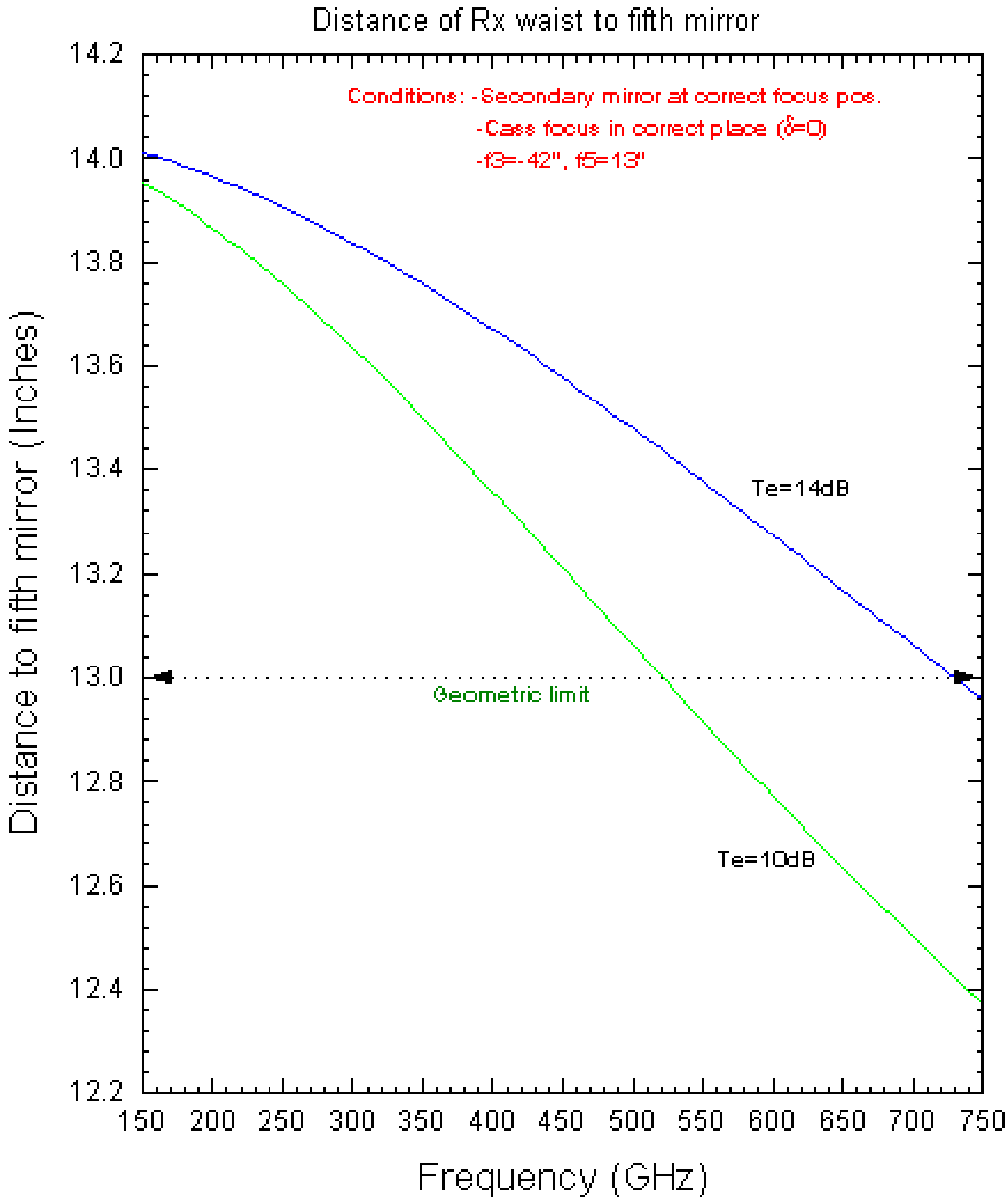
Figure 1 shows that the beam divergence can be accurately determined by placing a temporary flat sheet of metal of the fifth mirror. The second step might be to place the receiver in the correct theoretical focus position and map the beam on the secondary. As it turns out, this measurement is quite a bit easier than mapping the beam on the tertiary, due the relay optics hardware interference. The third step should be to set the chopping secondary to it's nominal focus position (+0.15) and do a focus curve on a planet. Once this is done sky-dips and a beam-maps would be useful in determining the receiver main beam efficiency, hot spillover and whether the beam is diffraction limited, the shape is correct and sidelobes levels small.

Addendum

The problem with the 230 GHz receiver optics is that the required beam is too ‘fast’. Changing the tertiary mirror to a -42” virtual focal length rather than the current -34” focal length will solve this problem as is shown below. The results are calculated for -10 and -14 dB edgetaper in the Secondary. Changing the focal length does in fact make the waist and it’s position in the elevation tube frequency dependent, which might not be a good idea!



.



Distance of Rx waist to fifth mirror
Conditions: -Secondary mirror at correct focus pos.
-Cass focus in correct place (δ=0)
-f3=-42", f5=13"
Te=14dB
Te=10dB
Geometric limit
Distance to fifth mirror (Inches)
Frequency (GHz)
14.2
14.0
13.8
13.6
13.4
13.2
13.0
12.8
12.6
12.4
12.2
150
200
250
300
350
400
450
500
550
600
650
700
750